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I.—*The Theory of the Winter Rains of Northern India.*—*By* Henry F. Blanford, F. R. S., *President, Asiatic Society of Bengal, Meteorological Reporter to the Government of India.*

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(With Plate I.)

It has long been a commonplace of meteorological hand-books, that the winter, or, as it is more frequently (but less accurately) termed, the north-east monsoon, is due to a reversal of those conditions which, in the summer season, set in movement a flow of air from equatorial regions towards the plains of Southern and Eastern Asia. But, beyond this general statement of fact, very little has been done towards working out the physical characteristics of this familiar phenomenon of the Indian winter; and such vague conceptions as are implied in the popular theory, leave entirely unexplained the well-known occurrence of rain, about Christmas time, in Upper India; a region, which, according to that theory, should then be the seat of a barometric maximum, the fount and source of the winter monsoon.

Since the establishment of a Meteorological Department under the Government of India, has rendered it possible to study the weather of India as a whole, from day to day, some insight has been gained into

the phenomena which precede and accompany the cold-weather rainfall of Northern India. In each of the annual reports on the Meteorology of India, in recent years, two or three instances of this cold weather rainfall have been described and illustrated at some length; and at the present time, although many important points still require further elucidation, it is at least possible to set forth some generalizations on the conditions which usher in the precipitation of the cold-weather rains, and on the probable source of the vapour which feeds them.

The four charts on Plate I exhibit the average distribution of atmospheric pressure in the months of November, December, January, and February. These charts, being based on the registers of duly verified barometers during the last seven years, corrected to a common standard and reduced to sea-level values from elevations, determined in all but a few exceptional instances, by actual spirit-levelling to the mean sea-surface, may be accepted as representing, with a near approximation to truth, the relative differences of pressure which characterize the winter months in India.* Certain characters common to all, may be regarded as distinctive of the season. The seat of highest pressure is in the neighbourhood of Peshawar. Whether this may be taken as indicating that the pressure on the highlands of Cabul is also greater than at similar elevations over the plains of India is, however, very doubtful. The situation of Peshawar on a plain of moderate extent, girt around with mountains, is such that the high pressure may be and very probably is a local effect of the cooled air, draining on all sides from the surrounding slopes and filling the basin from which its escape is much obstructed. A similar high pressure is shewn by some other stations near the foot of the N. W. Himalaya, of which Dehra is a notable example. The conditions of pressure at higher elevations over the Himalaya, will be noticed presently.

The next feature to be noticed is that, throughout the winter months, the axis of average high pressure on the plains and plateaux of India, occupies nearly the same situation as that of low pressure at

* Rigorously speaking any such representation must of course involve an element of unreality, which is the greater, the greater the difference of land levels in the area embraced in the chart; and, where, as in the case of India, large portions of the area differ by 2,000 feet and upwards, this element attains to some importance. Although it may not seriously impair the value of the chart as an illustration of the pressure-differences or potentials which maintain the system of wind-currents, the fact that the lower strata of air, resting on low alluvial plains, have no horizontal extension to the higher plateaux and cannot therefore be directly and immediately influenced by the atmospheric pressure there existing, is one that must be kept in view in discussing the relation of the winds to the pressure-distribution.

the opposite season. It extends from Upper Sind across Rajputana and the Central India plateau to Chutia Nagpur; the pressure along this axis declining, more or less irregularly, from N. W. to S. E. To the north of this ridge, a trough of relatively low pressure on the Gangetic plain separates it from the higher pressure along the foot of the Himalaya, and, in most years, the pressure in the Punjab is somewhat lower than that of Western Rajputana. On the other hand, to the south of this axis, the pressure falls gradually down to Cape Comorin and Travancore; being, however, considerably higher on the east than on the west coast of the peninsula. In fact, the isobars run down the peninsula almost parallel with the west coast. The low pressure area which runs down the west coast of the peninsula is prolonged to the north, up the Gulf of Cambay, producing a northward bend in the isobars of that region very similar to that shewn by them in the summer monsoon, but with reversed gradients.

Hence the cold weather distribution of pressure may be not inaptly described as a reversal of that which characterizes the summer monsoon; but, in the first place, the barometric differences between the extremes, and therefore the gradients effective in producing the monsoon current, are less than half as great, and, in the second place, the axis of high pressure across Northern India lies further south than its opposite in the summer monsoon. It lies well across the middle of the plateau to the south of the Ganges, instead of following the course of the river, or, as not unfrequently happens in the case of the summer trough of depression, somewhat to the north of it. Thus, both in summer and winter, low pressure tends to prevail in some part or other of the Gangetic valley and the Punjab; but in the summer the gradient declines towards the N. W., in the winter, to the S. E.

There is reason to believe that this normal distribution of pressure is restricted to the lower strata of the atmosphere, that is to say, to the stratum less than 7,000 feet in vertical thickness, measured from the sea-level. Thus, for instance, a row of stations on the plains of the Punjab and Ganges, ranging from Peshawar down to Purneah, shews a small, but decided, fall of pressure from N. W. to S. E., when all the mean readings are reduced to their equivalent values at the sea-level. But if the mean pressures of the hill-stations, Murree, Chakrata, and Darjeeling (all of which are between 6,000 and 7,000 feet, or a little over the latter elevation), be reduced to a common level of 7,000 feet, the gradient at that elevation is found to be slightly, but distinctly, reversed; Darjeeling, the easternmost station, shewing the highest pressure.

Sea-level Equivalents of Atmospheric Pressure on the Punjab and Gangetic Plains.

	November. ins.	December. ins.	January. ins.	February. ins.
Peshawar	30·098	30·174	30·161	30·115
Lahore	·023	·097	·084	·029
Delhi	·017	·089	·076	·020
Lucknow	·008	·078	·062	·006
Patna	29·995	·066	·060	·001
Purneah	·966	·028	·036	29·977

Equivalents at 7,000 *feet of Atmospheric Pressure at Stations on the outer Himalaya.*

	November. ins.	December. ins.	January. ins.	February. ins.
Darjeeling	23·404	23·380	23·339	23·320
Chakrata	·360	·340	·305	·281
Murree	·356	·332	·302	·268

It was shewn also in a paper on the winds of Northern India,* and in the *Indian Meteorologists' Vade Mecum*,† that, as between the Himalaya and Ceylon, the plane of neutral pressure, in January and February, is at a lower level than 7,000 feet; but not in the months of November and December; at least as an average condition. To this point, which is important, I shall presently return.

These facts of the pressure-distribution prepare us then to expect that which our wind-registers shew, *viz.*, that the winter monsoon is a much shallower, weaker, and more unsteady current than its correlative of the summer season. On the plains, the air is very calm in the Punjab; and, to the south and south-east, flows as a very gentle current, chiefly a day wind, drifting from the N. W. down the Gangetic plain; from north or N. E., and somewhat stronger, across the Central Indian plateau and the Satpuras; and from north or N. N. W. in Lower Bengal; then turning to N. E. or E. in the northern part of the peninsula, while, down the Bay of Bengal, it is pretty steady as the well-known N. E. monsoon. It turns, therefore, in an anticyclonic curve around the seat of maximum pressure in North Western India. Its rate of movement, its comparative steadiness, and its mean direction may be estimated from the following tables :—

* Phil. Trans. vol. 164, p. 563.

† Page 175.

Percentage of Wind-directions and Mean Daily Movement of the Wind at Stations in Northern India during the Winter Monsoon. (November to February.)

		Years.	Per cent.									Mean daily movement in miles.
			N.	N. E.	E.	S. E.	S.	S. W.	W.	N. W.	Calm.	
A North-Western India.	Rawalpindi	12	4	7	9	5	2	9	25	13	26	43
	Lahore	12	7	7	12	3	1	3	20	16	31	48
	Ludhiana	10	5	3	2	9	1	2	6	42	30	33
	Delhi	7	7	5	3	11	3	8	27	30	6	73
	Mooltan	12	8	21	1	10	4	14	2	15	25	47
	Jacobabad	4	17	14	9	5	1	3	6	13	32	48
	Bickaneer	4	10	18	8	7	9	20	5	7	16	68
B Gangetic Plain.	Roorkee	17	2	3	2	13	3	6	6	25	40	50
	Bareilly	12	3	5	4	8	1	7	17	39	16	68
	Lucknow	12	12	5	2	4	2	5	17	28	25	43
	Allahabad	12	9	6	9	2	3	6	24	11	30	38
	Gorakhpur	12	1	2	4	6	2	7	29	15	34	?
	Benares	16	4	6	8	3	3	11	39	12	14	64
	Patna	13	4	5	7	3	3	8	35	16	19	44
	Purneah	7	4	9	9	3	2	8	52	13	...	46
C Western India.	Hyderabad	4	41	7	...	1	2	10	5	19	15	158
	Kurrachee	21	9	18	16	4	4	14	18	9	8	229
	Rajkot	4	23	25	20	2	1	3	6	11	9	126
	Deesa	22	19	23	11	7	3	6	9	14	8	202
	Pachbudra	3	4	24	15	5	4	9	4	6	29	?
	Surat	4	12	17	18	10	2	12	14	11	4	132
D Central India Plateau and Satpuras.	Mount Abu	5	9	19	14	8	10	18	9	7	6	105
	Neemuch	4	8	12	12	15	16	16	9	12	?	153
	Indore	4	10	15	28	8	8	4	12	5	10	59
	Jhansi	10	2	35	6	8	2	15	4	11	17	51
	Nowgong	4	18	9	9	3	1	5	11	16	28	38
	Saugor	11	16	29	10	6	5	7	11	14	2	54
	Sutna	5	17	13	8	3	4	5	11	32	7	89
	Jubbulpore	11	24	18	7	6	16	6	8	9	6	55
	Pachmarhi	11	15	17	8	15	7	9	5	21	3	68
	Seoni	11	2	40	5	16	1	18	...	16	2	68
	Chikalda	5	25	4	4	11	18	12	7	17	2	110
E Chutia Nagpur.	Hazaribagh	14	10	6	4	4	4	6	23	40	3	118
F Lower Bengal.	Berhampore	14	24	8	3	2	2	8	16	25	12	41
	Calcutta	19	31	7	6	3	9	8	15	20	1	80
	Jessore	14	30	10	3	4	4	5	8	25	11	42
	Dacca	14	17	9	3	4	7	9	15	20	16	53

On comparing these tables with those for the summer monsoon, at the same stations, the relative greater frequency of calms, more especially in the Punjab and the Gangetic plains, the inferior steadiness of the wind in the prevailing quarter, and the very low absolute rate of its movement are strikingly apparent. The highest rates of movement are in Western India, as are also those of the summer winds, but the former vary from less than half to less than two-thirds of the latter, and the directions are much more variable.

It is further to be noticed that, while, at most stations, there is one direction of decided maximum, with some oscillation on either side (this being the local direction of the winter monsoon), at stations in the Punjab and the adjacent parts of the Gangetic plain, and also at Jhansi, Jubbulpore, Chikalda, Mount Abu, and Kurrachee, there is a distinct secondary maximum from an opposite quarter; and, at Mount Abu, Neemuch, and Bickaneer, a certain absolute preponderance of southerly winds. These are the winds which interrupt the winter monsoon and bring up the vapour that is condensed on the Himalaya as snow, and on the plains of Northern India as the winter rains of that region.

In fact, not only is the barometric gradient which characterizes the winter monsoon less highly inclined than that of the opposite season, and the vertical height to which it prevails (the elevation of the neutral plane) considerably less, but it is more frequently reversed, and especially so in January and February; and, as a temporary phenomenon, barometric minima, with the usual vortical systems of winds, occasionally appear in Northern India. On such occasions, rain almost invariably follows, beginning generally over the mountains that hem in the Punjab, and on the plains at their foot, and thence extending to the east and south-east; while the barometric depression moves eastward, and cold westerly winds, bringing fine weather and a wave of high barometric pressure, follow up in the rear.

In the majority of cases the history of which has hitherto been traced out, the barometric minimum first appeared, and was apparently formed in some part of the great north-western plain, most frequently in the Punjab or Upper Sind; but, in some cases, in Western Rajputana. Mr. F. Chambers has put forward the suggestion* that these minima travel hither from regions further west, from the plateau of Beloochistan or the still loftier mountain-tract of Afghanistan; but this seems to be a misapprehension. We have, indeed, no observatory in Afghanistan, and it may be long before any systematic observation is possible in that interesting, but turbulent, country. But an observatory has existed for some years past at Quetta, and, although its elevation is

* Nature, vol. xxiii, p. 400.

not known with sufficient precision to admit of its barometric register being reduced to terms comparable with those of the Sind and Punjab stations, I have compared the oscillations of the Quetta barometer with those in the valley of the Indus, when barometric minima have appeared in Upper Sind, and find that, with two very doubtful exceptions, in January and February 1880, any fall of pressure at Quetta was either simultaneous with the fall in Sind, or somewhat later. In one of these exceptional instances, there was a slight fall at Quetta two days, and in the other one day, before it took place at Jacobabad; but on both occasions, the great fall, when the minimum was established in Upper Sind, was simultaneous at both stations. In such cases as that of the 25th January 1878 (when the minimum first appeared at Deesa) and those of January, February, and March 1881 (when a barometric depression which had existed in Western Rajputana throughout the cold season, was simply intensified immediately prior to the rainfall), there could be no question of a depression travelling from the westward.

But it is not only in North-Western India even, that barometric minima are occasionally formed in the winter months: in the case of the rain of the 10th to 13th January 1878, it first appeared on the western half of the Deccan plateau; in that of the 10th February 1879, a long trough-shaped depression ran through the heart of India from Belgaum to Lucknow, and, in that of the 15th to 18th February 1880, it was first established in the Central Provinces, whence it was transferred to the Punjab; and the distribution of pressure, in Northern India, became strikingly similar to that which characterizes the rainy season.

There is, then, no reason to doubt that, notwithstanding that Northern India is in general and on an average an area of high pressure in the winter season, relatively to lower latitudes, this condition is by no means constant or lasting. The atmospheric pressure, in extra-tropical India, more frequently than that of the peninsula, occasionally falls below that prevailing over the seas to the south, causing vapour-bearing currents to pour in from that direction; and these currents, in ascending around the seat of minimum pressure, chiefly on the east and north of the minimum, condense that vapour as rain (and on the hills as snow). This is a more or less regularly recurrent feature of the winter season.

Of the conditions which determine the formation of these barometric minima, but little can be positively asserted in the present state of our knowledge. That they do not originate in a local excess of temperature in the lower atmospheric strata, is abundantly apparent; the rise of temperature that, in general, precedes the rainfall, and is accompanied

with a rise in the relative and absolute humidity of the air, is simultaneous with the setting in of the southerly wind; and this change of wind implies a pre-existing reversal of the barometric gradient, which is the phenomenon to be accounted for. The following considerations may, however, be worthy of attention as tending to throw some light into the prevailing obscurity.

It has been shewn above, that, at the very moderate elevation of 7,000 feet over the outer Himalaya, the barometric gradient is on an average slightly, but distinctly, reversed. At greater elevations, it is most probable that the reversal is more decided, for I have shewn elsewhere* that at Leh (11,500 feet) the pressure in February is at its annual minimum, and the wind-registers of all our hill-stations establish the fact that, throughout the winter months, the prevailing winds are southerly. This preponderance is no doubt, in some measure, perhaps mainly, due to the fact that the observations are those of 10 A. M. and 4 P. M. only; at which hours the diurnal up-draught of the mountain winds, in an otherwise still atmosphere, is fully active. But I have myself witnessed at Darjeeling, in December, the effects of a strong steady current, sweeping overhead from the south-west, clothing the snowpeaks with cloud-banners. This strong southerly wind is, however, exceptional; and is that which precedes rain; and although it is not improbable that, at great elevations, there is a more or less steady flow of air towards Central Asia, to feed the outflow, at low levels, from the anticyclone which, as we know, normally exists in the winter over Northern and Central Asia, there is no reason to question that, up to a considerable elevation over Northern India, the more usual condition is one of comparative stillness or at most of light movement. And, in this state of the atmosphere, even a feeble local action, tending to reduce the density and therefore the pressure, may suffice to set up a centripetal influx of air which may in a short time produce a well-developed barometric minimum. How this may be brought about will be shewn presently.

The southerly surface winds that are invariably the precursors of precipitation, are not merely local; they prevail also far to the south, indeed over a great part of India; and they arrive charged with vapour gathered both from the sea and from the warmer land-surface of more southerly regions.

It seems not improbable, then, that the ulterior conditions which give rise to the winter rains, may have their seat in the more elevated or middle region of the atmosphere; and we must look to the formation of cloud as the condition which, by disturbing the thermal equilibrium

* *Indian Met. Memoirs*, vol. i, p. 224.

of the atmosphere, determines a convective current with a cyclonic circulation, and a barometric minimum. The prevailing calmness of the Punjab atmosphere, combined with a high degree of relative humidity in the winter months, affords conditions not unfavourable to this action.

Before proceeding further with this discussion, it will be of advantage to consider the distribution of the winter rainfall, its distribution both in time and space.

For this purpose it will not be necessary to illustrate the subject in great detail, and, instead of giving the means of individual stations, I shall summarize the data in the form of the averages of large areas. The following table gives the average amount of the fall in each of the months from November to March.

Summary of the Winter Rainfall of Extra-tropical India.

	Stations.	Inches of rainfall.					
		November.	December.	January.	February.	March.	Total.
Peshawar and Derajat	5	0·46	0·51	0·65	1·06	1·29	3·97
Hazara and Patwar	4	1·06	1·50	1·57	2·64	2·66	9·43
The four doabs	11	0·18	0·60	0·77	1·15	1·14	3·84
Eastern Punjab	11	0·07	0·58	0·91	0·95	0·95	3·46
Kangra, Sirmoor and Kumaon	11	0·18	1·01	2·10	2·80	2·54	8·63
N. W. P. & Oudh, Western half*	24	0·06	0·33	0·81	0·66	0·57	2·43
Ditto ditto, Eastern half	15	0·10	0·15	0·66	0·55	0·34	1·80
North Behar and Bhagalpore	5	0·08	0·10	0·58	0·53	0·45	1·74
Northern Bengal	8	0·34	0·12	0·43	0·79	1·18	2·86
Assam and Cachar	13	0·95	0·36	0·64	1·35	3·45	7·00
Upper Sind	3	0·08	0·16	0·23	0·37	0·44	1·28
Lower Sind, Cutch and Gujarat	18	0·08	0·07	0·11	0·16	0·06	0·48
Rajputana	20	0·09	0·27	0·11	0·31	0·15	0·93
Central India, &c.	24	0·16	0·19	0·42	0·40	0·23	1·40
Mirzapore and Chutia Nagpur	14	0·22	0·13	0·58	0·78	0·57	2·28
Lower Bengal	15	0·50	0·17	0·48	1·07	1·60	3·82

The above table includes the whole of extra-tropical India, and it is only in a portion of this region that the cold weather rainfall can be regarded as a well-marked and regularly recurrent phenomenon; having a distinct maximum, that is to say, in the winter or spring months and equally defined minima before and after. The variations, shewn in the above table, are considerable, both as regards the total amount and the epoch of the maximum. It is on the N. W. Himalaya

* The meridian of Lucknow is taken as the boundary.

and on the hills of the Northern Punjab that these rains are most copious, and that the maximum falls latest; the precipitation frequently taking the form of snow at all but the less elevated stations. In the extreme north-west, they attain their maximum in March and April; for the April rainfall (not shewn in the table) is about equal to that of March at Peshawar and in the hills of Hazara, while that of May and June is insignificant. But south of the Salt Range, and on the plains of the Eastern Punjab, the rainfall of February and March exceeds that of April. Still further to the south-east, throughout the greater part of the Gangetic plain, the maximum occurs still earlier, *viz.*, in January; and this holds good as far as Behar and the confines of Northern Bengal. This anticipation of the maximum is not due to the January rainfall of the Gangetic plain being heavier than that of the Punjab. On the contrary, it is rather less: but the decrease in a south and S. E. direction is much less rapid in January than in the subsequent months. In Northern Bengal, even the January maximum has vanished; and while the average rainfall of that month is only slightly less than in Behar and the eastern part of the N. W. Provinces, that of February is higher, and that of March shews a further considerable increase. So far, the course of the variation seems to resemble that of the N. W. Punjab; but the further steady increase of the fall in April, May, and June shews that this resemblance is fallacious, and that we have here to do with a phenomenon of a different order, *viz.*, the storm precipitation of the spring months, the characteristics of which are still more pronounced in the more easterly province of Assam. As a well-marked feature of the local meteorology, the cold weather rainfall does not extend, in an easterly direction, beyond the province of Behar.

Turning now to the regions somewhat further south, but still, for the most part, without the tropic, we see that in Upper Sind the total fall of the five months is very small, notwithstanding that it represents nearly one-third of that of the year; and also that, as in the Derajat, it reaches its maximum in March. In Lower Sind, Cutch, and Gujarat, the whole precipitation of the season is insignificant; but a maximum is still faintly indicated in February, and the same is more strongly marked in Rajputana, where the fall is about double as great. In Rajputana, it would appear that the December rainfall is almost as great as that of March; but this is mainly due to an exceptionally heavy rainfall in December 1877,* combined with the fact that the Rajputana registers extend over a shorter period than those of most other parts

* On this occasion nearly five inches of rain were registered at Banswara, between 3 and 4 inches at Jhalrapatam and Ulwar, and over 2 inches at Kotah, Deoli, and Bhurtpore.

of the country. I do not think, therefore, that, on the average of a long period of years, the November rainfall of Rajputana would be found to follow a different law of distribution from that of other provinces around. In Central India, including those portions of the Central Provinces and the N. W. Provinces that extend between the Jamna and the Satpura range, the total fall is again higher, with a maximum in January and February; and, still further east, in Mirzapore, South Behar, and Chutia Nagpur, it is again greater, with the maximum in February; but this apparent retardation of the maximum is evidently due to the inclusion of the early spring storms which in Chutia Nagpur become of relatively greater importance; and this is rendered further evident in the table for Lower Bengal.

The conditions which determine the storm precipitation of the spring months will be noticed elsewhere. Meanwhile, it results from the above analysis that the cold weather rainfall, as here considered, is that which takes place chiefly on the north and east of the barometric depressions, which are occasionally formed, in the winter months, in North-Western India. It is most copious where normally the winter temperature is lowest, *viz.*, on the N. W. Himalaya. It decreases rapidly to the south, and less rapidly to the south-east, and, in this latter direction, it blends into and becomes with difficulty distinguishable from the rainfall of the spring storms, which are, however, a phenomenon of a different order.

Having thus defined the area and noticed the general characteristics of the winter rainfall of North-Western India, I will return to the question of the origin of those barometric depressions which have been shewn to be the immediate precursors of the precipitation, or perhaps rather of simultaneous formation. The area above defined as that of the winter rains, is identical with that in which, as has long been known, the relative humidity of the air, instead of diminishing towards the interior of the country, increases with the increasing distance from the sea-coast. On page 203 of the *Indian Meteorologist's Vade Mecum* (Part II, para. 109), I described this phenomenon as follows: "In the maritime provinces (of India) there are but one (annual) period of maximum and one of minimum humidity; in the Punjab and in Central India and the North-Western Provinces, there are two annual maxima and two minima; and in the drier part of the first named province, the winter is the dampest season of the year * * * *. Stations on the coast line have, at all times of the year, a higher degree of relative humidity than those on the plains of the interior. But the rate of increase is very different at different seasons; and in consequence of the greater cold of Upper and extra-tropical India, in the first three months of the

year, the rule of increasing dryness with increasing distance from the coast holds good inland, only as far as Behar; and thence to the Punjab the relative humidity of the atmosphere increases steadily. It appears to be higher also through Central India, north of the Satpuras, but the meteorological statistics of this tract have not yet been sufficiently worked out to enable us to fix the limits of the area of higher winter humidity."

The above passage was written in 1876, only a year after the meteorological data for the whole of India had been, for the first time, concentrated in one central office, and when the system of observation had been but recently extended to many stations in Rajputana and Central India. It is, therefore, desirable to set forth, in a tabular form, some excerpts from the further evidence which has since been put on record; and, to this end, I give, in the following tables, first, the absolute humidity of the air as represented by the proportion of vapour in 1,000 parts (volumes) of air, second, the relative humidity, and, third, the cloud proportion (in thousandths of the sky-expanse*) in each of the six months November to April for four series of stations, three passing successively from east to west (or north-west) and representing respectively the Himalaya, the alluvial plain, and the plateau which extends between the latter and the Satpura range; and the fourth passing from south to north, beginning with stations south of the Satpura range, and terminating in the Punjab.

* The figures of the two latter tables are extracted from those of the average values of the several meteorological elements given in the Report on the Meteorology of India in 1881.

Mean Absolute and Relative Humidity of the Air and Proportion of Cloud in Northern India in the Winter and Spring Months.

Stations.	Elevation in feet.	Miles from Sea.	Volume of vapour in 1000 of air.						Percentage of saturation.						Cloud proportion $\frac{x}{1000}$.					
			November.	December.	January.	February.	March.	April.	November.	December.	January.	February.	March.	April.	November.	December.	January.	February.	March.	April.
Darjeeling,	6,712	375	12	9	9	10	12	15	75	73	78	78	71	77	439	425	569	592	531	614
Ranikhet,	6,069	730	10	8	8	8	10	11	58	56	59	60	55	47	122	270	344	461	378	335
Chakrata,	7,050	750	9	6	6	7	8	10	58	52	61	58	54	47	153	351	413	539	465	385
Murree,	6,344	750	7	6	5	6	8	10	43	49	48	57	51	50	315	455	516	541	595	520
Saugor Island,	6	0	22	17	18	22	27	32	74	73	75	77	78	80	248	180	180	188	356	474
Calcutta,	18	65	20	15	14	18	22	28	74	71	70	69	69	73	220	196	127	192	225	265
Jessore,	33	95	20	16	14	16	21	27	68	63	60	55	55	62	210	132	158	176	274	336
Berhampore,	66	176	18	14	12	14	18	22	72	71	69	65	58	62	257	194	215	192	291	320
Purneah,	125	295	17	14	12	13	16	21	70	69	66	59	55	56	93	107	122	113	140	150
Patna,	179	307	15	12	12	13	14	16	57	60	60	55	43	39	176	201	249	275	315	233
Benares,	267	368	13	10	10	11	12	13	62	64	63	57	43	36	120	162	222	240	217	184
Allahabad,	307	430	14	12	11	12	13	15	63	68	67	60	46	36	92	163	193	222	189	143
Lucknow,	369	550	12	10	10	11	14	15	53	58	59	55	46	37	91	192	282	333	291	222
Bareilly,	568	665	13	10	10	11	14	15	59	64	64	61	53	41	67	177	271	309	261	177
Roorkee,	887	690	12	10	10	10	12	12	57	64	65	62	52	36	87	222	285	358	264	227
Ludhiana,	812	690	10	9	9	11	12	15	51	62	63	63	57	50	155	249	333	389	386	264
Sialkot,	829	717	11	10	10	10	13	14	56	68	68	67	58	42	214	309	404	443	448	367
Rawalpindi,	1,652	730	10	9	8	9	12	16	62	67	67	68	63	59	199	305	388	442	439	382

Mean Absolute and Relative Humidity of the Air and Proportion of Cloud in Northern India in the Winter and Spring Months (Continued).

Stations.	Elevation in feet.	Miles from Sea.	Volume of vapour in 1000 of air.						Percentage of saturation.						Cloud proportion $\frac{x}{1000}$.					
			November.	December.	January.	February.	March.	April.	November.	December.	January.	February.	March.	April.	November.	December.	January.	February.	March.	April.
Hazaribagh,	2,010	205	12	10	9	10	10	12	53	52	51	44	36	32	203	192	236	211	258	262
Sutna,	1,040	450	10	8	8	9	8	10	42	48	47	41	29	25	137	162	216	292	262	252
Jhansi,	855	490	10	9	9	10	11	12	39	45	47	42	34	28	29*	38*	66*	75*	40*	46*
Neemuch,	1,639	280	9	7	7	8	9	11	35	38	35	35	30	26	63	149	151	310	234	230
Ajmere,	1,611	410	11	9	9	10	12	15	45	49	47	46	42	38	101	152	245	273	280	249
Raipur,	960	270	16	12	12	14	13	15	60	56	55	51	41	36	168	127	132	112	165	209
Nagpur,	1,025	350	14	12	11	12	11	13	52	50	49	42	32	28	257	238	233	194	255	305
Akola,	930	270	13	11	10	10	11	10	50	48	44	37	28	22	134	146	139	199	127	128
Jubbulpore,	1,351	420	13	10	11	12	13	13	57	56	58	53	40	32	171	197	218	238	246	217
Sutna,	1,040	450	10	8	8	9	8	10	42	48	47	41	29	25	137	162	216	292	262	252
Nowgong,	757	515	11	10	9	10	11	14	50	56	52	48	37	31	91	153	182	365	240	205
Jhansi,	855	490	10	9	9	10	11	12	39	45	47	42	34	28	29*	38*	66*	75*	40*	46*
Agra,	555	540	11	9	9	10	11	13	43	53	55	49	40	31	54	131	167	245	175	144
Delhi,	718	615	11	9	9	10	12	13	46	53	55	52	45	34	80	176	309	334	299	269
Ludhiana,	812	690	10	9	9	11	12	15	51	62	63	63	57	50	155	249	333	389	386	264

* The estimates of cloud proportion are probably affected by a large personal equation.

The above table confirms and justifies the description already quoted from the *Vade Mecum*, and also the generalization just given, that the area of the winter secondary rainfall maximum coincides with that in which there is also a winter secondary maximum of relative humidity. But it also brings into prominence some further facts, which assist in throwing much light on the causes of the rainfall. In the first place, it is to be noticed that the increase of the relative humidity of the later months, as we proceed from Behar towards the Punjab, is due, solely, to the fall of temperature; the absolute humidity being almost constant; but the latter is decidedly lower on the high ground of Central India and Rajputana, south of the Gangetic plain, than on the latter and in the Punjab. These two facts, *viz.*, the uniformity of the absolute humidity over the riverain tract, and its decrease on the higher ground to the south, indicate that it is mainly dependant on local evaporation; being, in fact, furnished by the rivers, the undried swamps left by the autumnal floods, and, in no small degree, probably, by irrigation and the rich vegetation of the green winter crops. In the second place, it is to be observed that this riverain tract also coincides with the region of lower normal pressure, to the north of the axis of maximum pressure, shewn on the normal baric charts, on Plate II. And lastly, the tendency to cloud formation follows, on the whole, the same laws of distribution as the relative humidity of the lower atmosphere, with, however, this important exception; that, except in April and to a slight extent in March, it is lower in the neighbourhood of the coast (in Lower Bengal), notwithstanding the higher relative humidity of the lower atmosphere, than in the Upper Provinces, where the rainfall generally originates.

Now putting together the several facts thus independently elicited from the study of our registers, we arrive, I think, at the outlines of a consistent theory of the production of the winter rainfall. We have, in the first instance, steady evaporation over an extensive moderately humid tract, at a comparatively low temperature, it is true, but in an atmosphere, the stillness of which allows of steady diffusion of the vapour to high levels, and the consequent formation of cloud. The slight disturbance of the baric equilibrium which follows (since the vertical decrease of temperature in a cloud-laden atmosphere is slower than in a clear atmosphere), is succeeded by a gentle indraught of warmer and more humid air from the south; for the Himalaya bars access to northerly winds. A vortex is then rapidly formed, accompanied with an increased cloud-formation, and speedily followed by precipitation; which takes the form of snow on the hills, and of rain over the river plains. The rainfall is invariably followed by a cool wind, and a wave of high barometric pressure from the west, which I can only

attribute to a drainage of cool heavy air from the valleys of the hills surrounding the Punjab and the high lands of Beloochistan and Afghanistan; air cooled by the precipitation on the mountains.

If the above view be true, the stillness of the atmosphere, combined with the presence of a moderate evaporation, must be accepted as the condition which primarily determines the formation of barometric minima and the winter rains of Northern India. And this stillness is obviously due to the existence of the lofty mountain ranges which surround Northern India, leaving free access to the plains open only to the south.

Were the Himalayan chain absent and replaced by an unbroken plain, stretching up to the Gobi desert, it is probable that the winter rains of Northern India would cease; any local evaporation in the Punjab and Gangetic valley would be swept away by strong dry N. E. winds blowing from the seat of high pressure, which, in the winter months, lies in Central Asia; and instead of the mild weather and gentle breezes which now prevail at that season, on the Arabian Sea, it would be the theatre of a boisterous and even stormy monsoon, such as is its local equivalent of the China Seas. Other and even greater changes of climate, that would supervene on the suppression of the Himalayan range and the consequent alteration of the summer monsoon, its precipitation, and the course of the land drainage thereby fed, it would be beyond the province of my present subject to discuss.

II.—*Descriptions of some new Asiatic Diurnal* Lepidoptera; *chiefly from specimens contained in the Indian Museum, Calcutta.*—*By* Frederic Moore, F. Z. S., A. L. S. *Communicated by the* Natural History Secretary.

[Received May 14th,—Read June 4th, 1884.]

Family NYMPHALIDÆ.

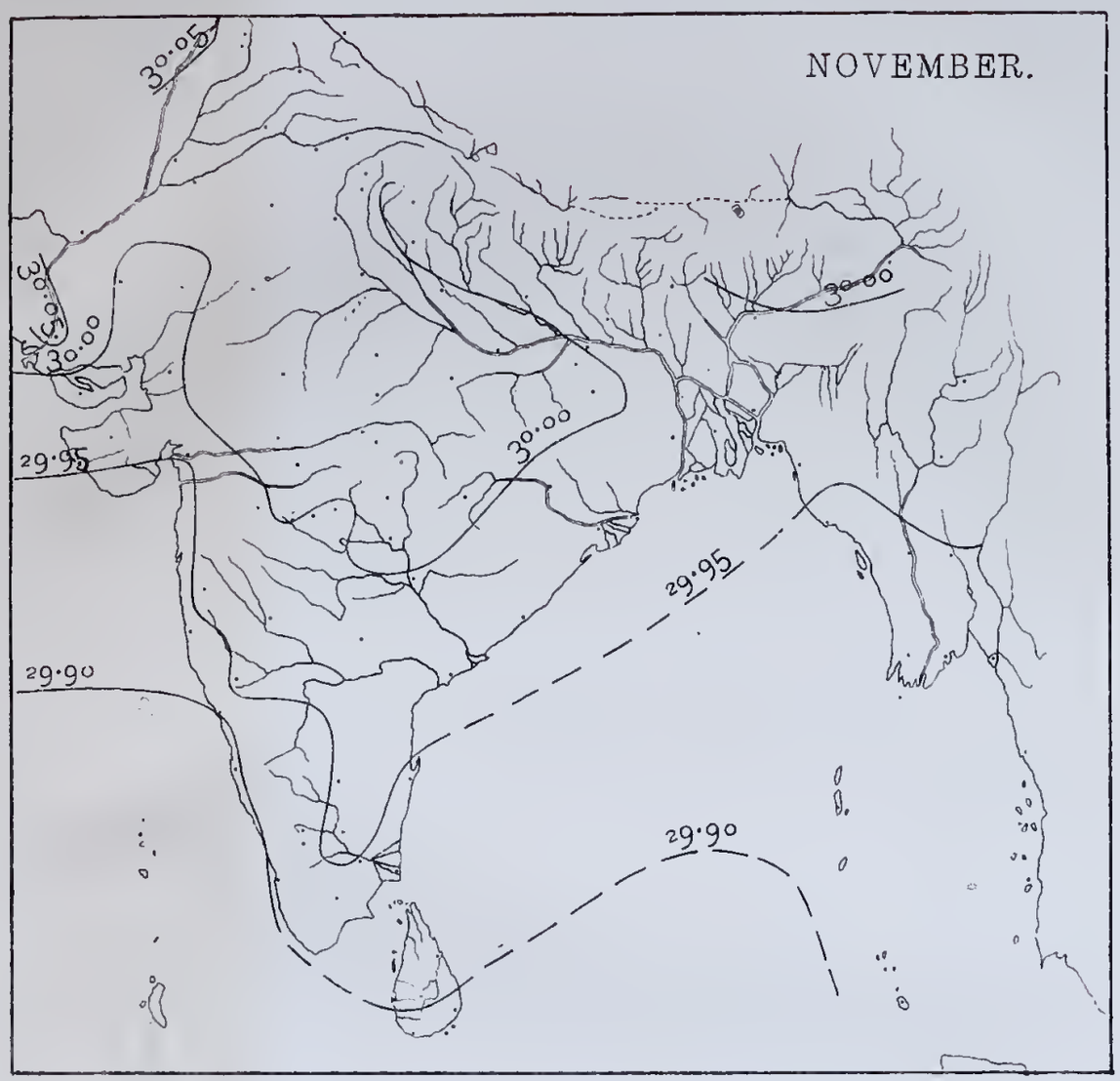
Subfamily Satyrinæ.

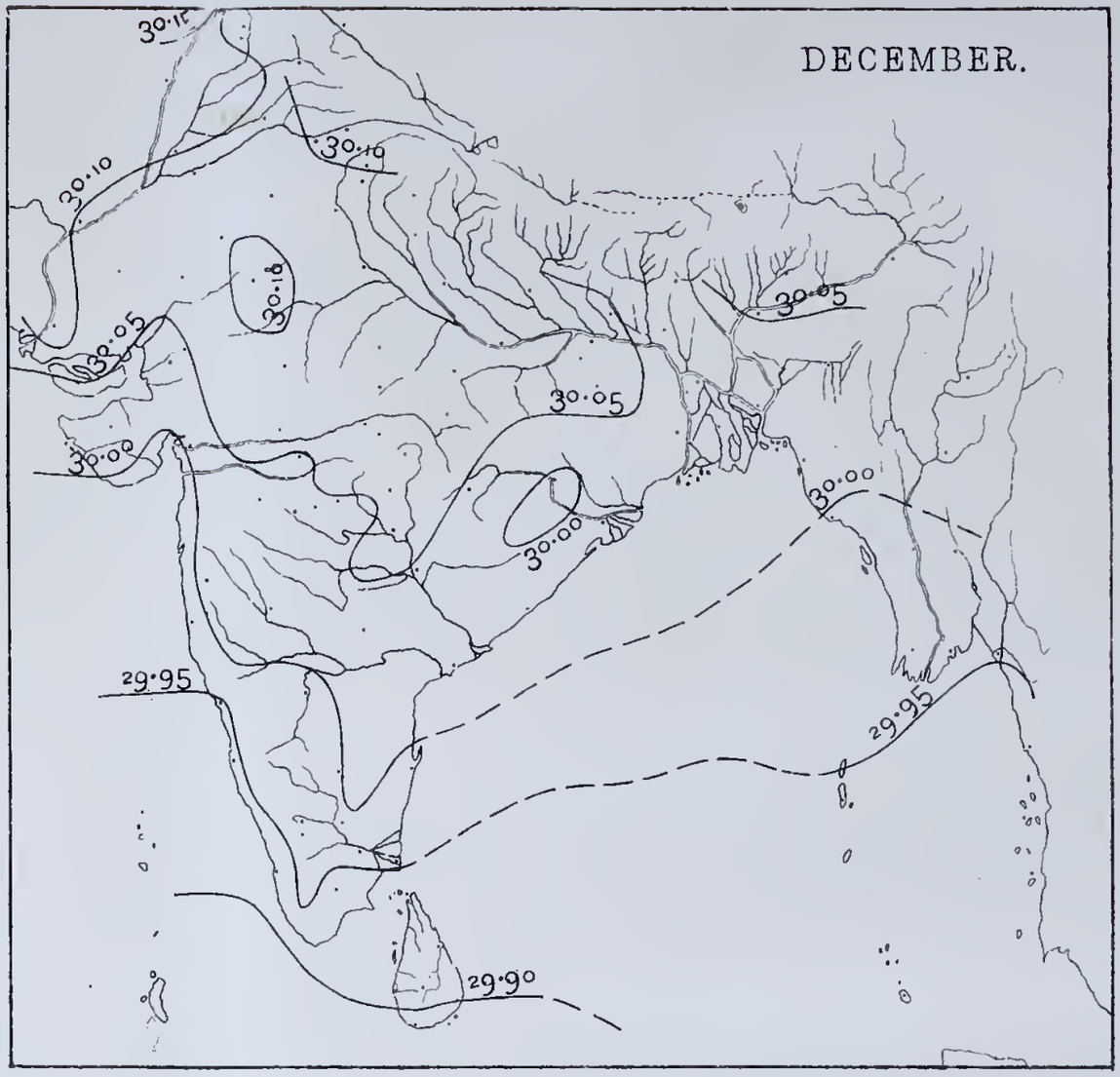
Genus Ypthima, Hübner.

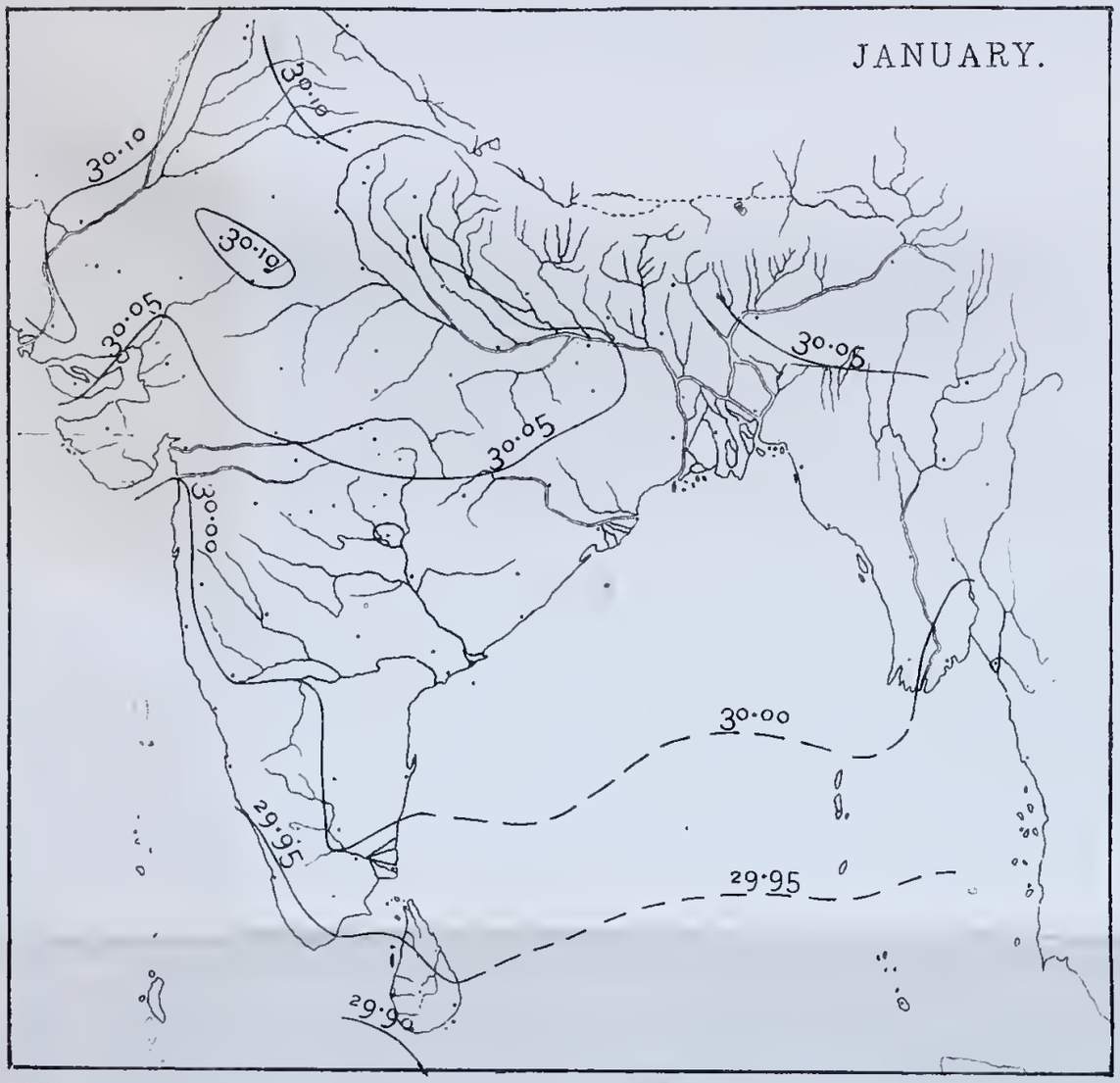
Ypthima mahratta, n. sp.

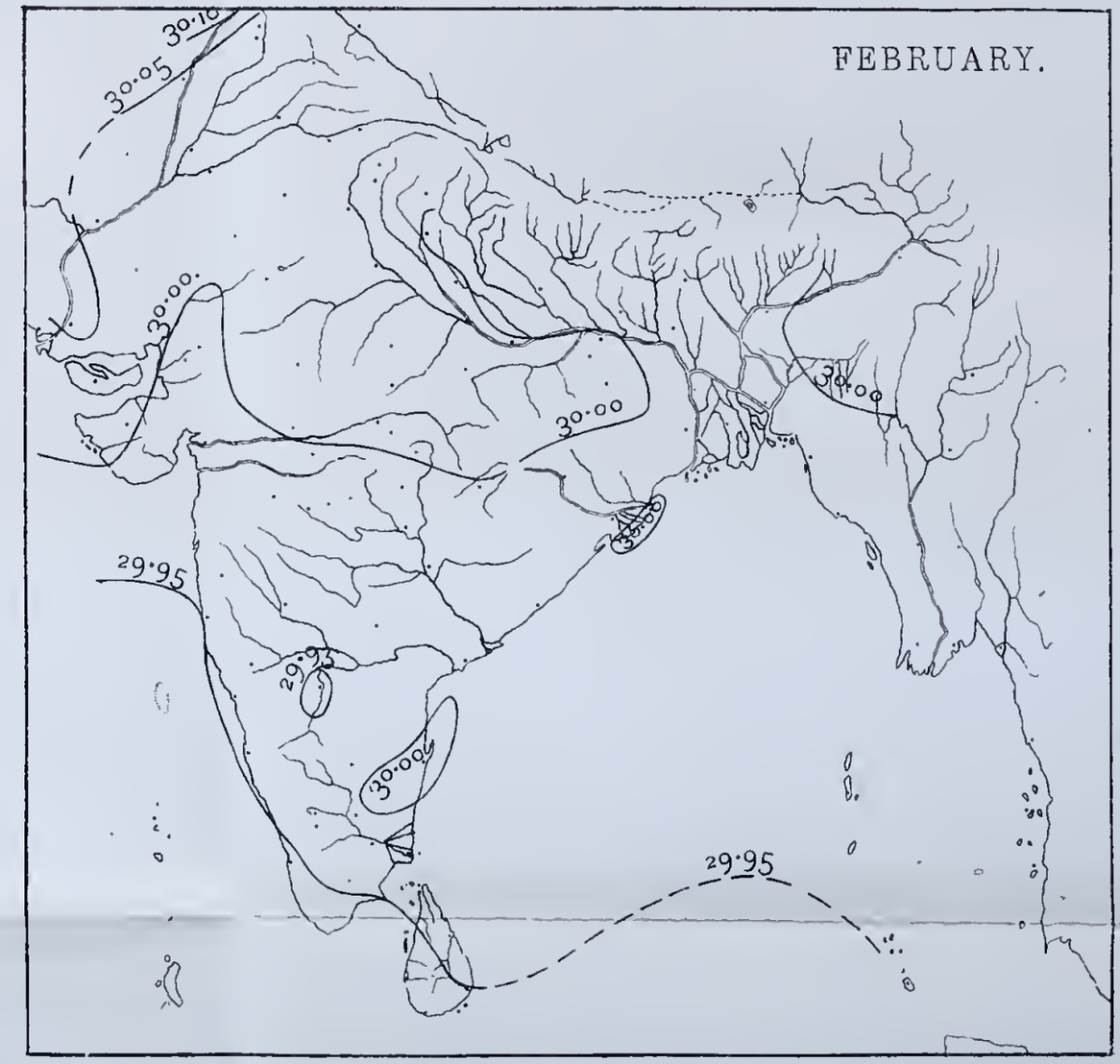
Male and female. Upperside brown; forewing with a subapical bipupilled ocellus; between which and the outer margin is a pale brown curved fascia as in *Y. newara:* hindwing with a very small subanal unipupilled ocellus.

Underside pale whitish-brown, very numerously covered with short delicate pale brown strigæ, which are uniformly disposed: forewing with









Lithographed at the Survey of India Offices, Calcutta, August 1884.

ISOBARIC CHARTS OF AVERAGE PRESSURE.